Electroweak Corrections to Associated Higgs-bottom quark production

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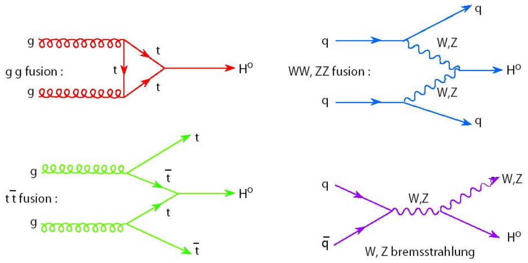
Outline

1. Higgs Production
   - SM Higgs Production
   - Beyond SM Higgs Production

2. Weak Corrections to $bg \to bH$
   - Calculation
   - Results for Tevatron and LHC

SM Higgs Production

- Dominant production channels.



- gg fusion : Enhanced coupling (top Yukawa)

$$y_t \sim \frac{m_t}{v} \sim g\frac{m_t}{m_W}$$

- Dominates [even though loop supressed!]

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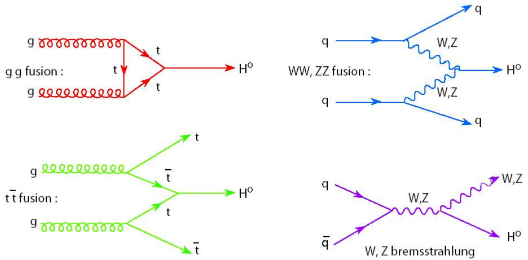

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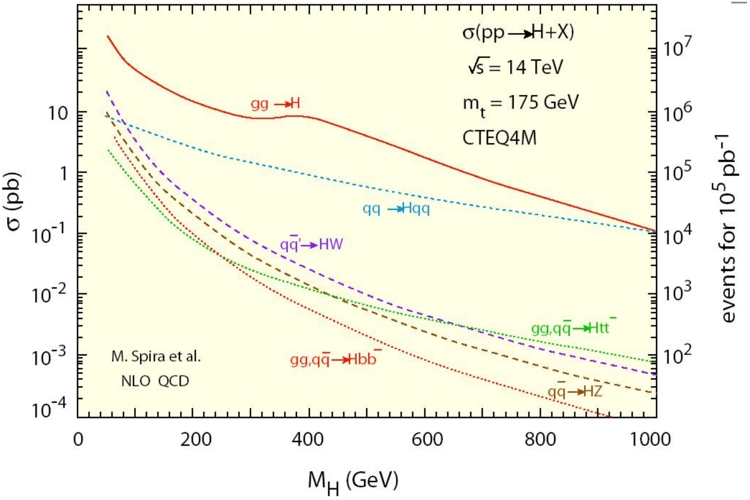
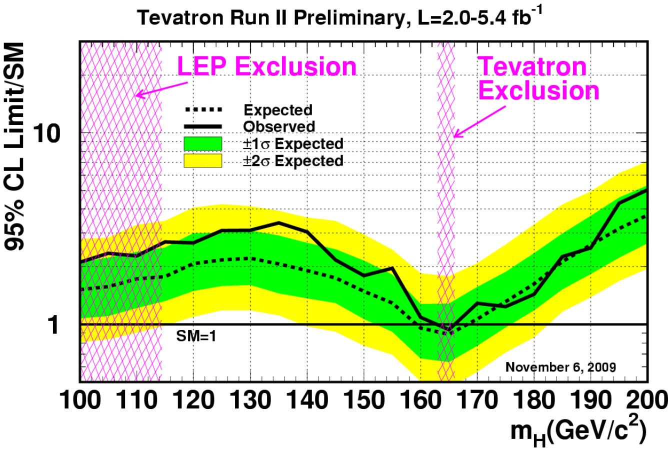
SM Higgs Production



SM Higgs Status



Bottom Yukawa?

- In SM, $y_b \sim m_b/v$ supressed.
- In MSSM : 2 Higgs

$$\begin{aligned} H_u &= \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \\ H_d &= \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix} \end{aligned}$$

- 8 DOF, EWS breaking $\rightarrow$ 3 Golstone bosons, 3 real Higgs h_0, H_0 , A_0 and 1 complex Higgs H^+
- SU(2) invariant superpotential :

$$W = \left[y_{u_{ij}} \left(\overline{u}_{i,L} Q_j \cdot H_u \right) - y_{d_{ij}} \left(\overline{d}_{i,L} Q_j \cdot H_d \right) \right]$$

Bottom Yukawa in MSSM

- Yukawa interaction

$$\mathcal{L}_{int} = -\frac{1}{2}\frac{\partial^2 W}{\partial z_i \partial z_j}\psi_i \cdot \psi_j + \mathrm{h.c.}$$

- Diagonalize Higgs field to get h_0 , H_0 etc

$$h^0 = \sqrt{2}\,(\phi_u \cos\alpha - \phi_d \sin\alpha)$$

- Bottom Yukawa :

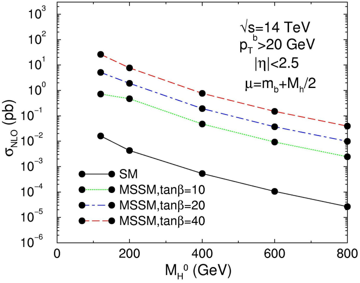
$$\begin{aligned}
\mathcal{L}_{bottom\ int} &= -y_b \phi_d \left(\overline{b} \cdot b\right) + \mathrm{h.c.} \\
&\sim -m_b \frac{\cos\alpha}{v_d} h^0 \left(\overline{b}_i \cdot b_j\right) + \mathrm{h.c.}, \quad \tan\beta = \frac{v_u}{v_d} \\
&\sim -\frac{e m_b}{m_W \sin\theta_w}\frac{\cos\alpha}{\cos\beta} h^0 \left(\overline{b} \cdot b\right) + \mathrm{h.c.}
\end{aligned}$$

Bottom Yukawa in MSSM

- Decoupling limit $(m_A \gg m_Z)$: $\beta = \alpha - \pi/2$.

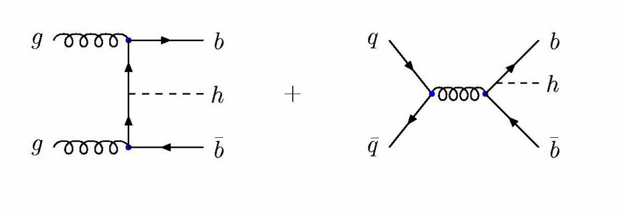
$$\mathcal{L}_{bottom\ int} \sim -\frac{e m_b}{m_W \sin\theta_w} \frac{\cos\alpha}{\cos\beta} h^0 \left(\bar{b} \cdot b\right) + \mathrm{h.c.}$$
$$\sim (\tan\beta)\, \mathcal{L}^{SM}_{bottom\ int}$$

- $pp \to b\bar{b}h$



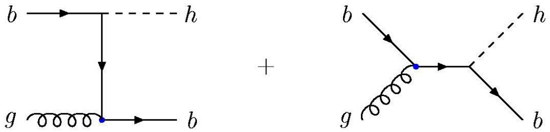
Schemes : 4FNS

- 4FNS
  - Fixed flavor number (= 4) [No bottom in initial state]
  - Good for exclusive cross-section (both b jets tagged)
  - Large logs from phase space integration $\sim \ln(\mu^2/m_b^2)$. $\mu \sim \mathcal{O}(m_H)$



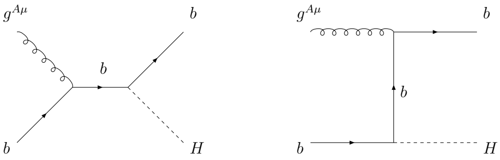
Schemes : 5FNS

- Resum the logs and absorb them in bottom PDF.
- Inclusive modes have larger cross-section but also larger backgrounds.
- Lowest order diagrams $\leftrightarrow$ Zero p_T
- Can be used for inclusive or semi-inclusive cross-section (no or one b tag)



Tree level $bg \to bH$

- Lowest order :



- Differential cross-section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = -\frac{\alpha_s(\mu)}{24s^2}\left[y_b(\mu)\right]^2\left[\frac{M_H^4 + u^2}{st} + \ldots\right]$$

- … terms supressed by powers of m_b.
- Our analysis, $m_b \neq 0$.

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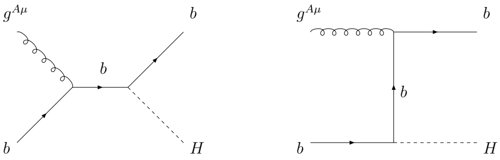

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What happens for $m_b \to 0$

- Tree level $\mathcal{M}_0 \propto y_b \propto m_b$
  $\Rightarrow \mathcal{M}_0$ vanishes !!
- One-loop corrected amplitude

$$\begin{aligned}\mathcal{M} &= |\mathcal{M}_0 + \mathcal{M}_1|^2 \\ &= |\mathcal{M}_0|^2 + 2\mathcal{M}_0\mathcal{M}_1^* + |\mathcal{M}_1|^2 \\ &\to |\mathcal{M}_1|^2\end{aligned}$$

- Only a few diagrams contribute (not supressed by bottom Yukawa).
- Significant contribution in SM ($\sim 8\%$) [Mrenna and Yuan, Phys. Rev. D 53, 3547–3554 (1996)]

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$m_b \neq 0$ case

- $|\mathcal{M}_0|^2 \Rightarrow \mathcal{O}(\alpha_s G_F)$ [tree level, small in SM]
  $|\mathcal{M}_1|^2 \Rightarrow \mathcal{O}(\alpha_s G_F^3)$ [large in SM, approx same in MSSM]
  $\mathcal{M}_0 \mathcal{M}_1^* \Rightarrow \mathcal{O}(\alpha_s G_F^2)$ [small in SM, can be large in MSSM]
- **Renormalization** :
  - Input parameters : α, M_Z, G_F
  - Calculate 1-loop corrected W mass

$$M_W^2 = \frac{M_Z^2}{2}\left[1 + \sqrt{1 - \frac{4\pi\alpha}{\sqrt{2} G_F M_Z^2}(1 + \Delta r)}\right]$$

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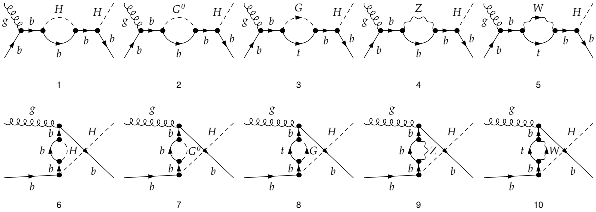
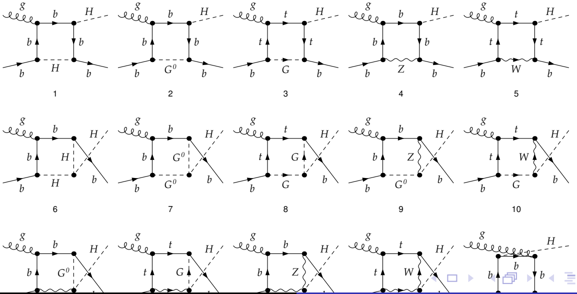
Loop Calculations $bg \to bH$

- Automized Calculations
  - FEYNARTS to generate diagrams
  - FORMCALC for calculation of amplitudes [Passarino-Veltman functions]
  - LOOPTOOLS for numerical computation of PV integrals
- Checks :
  - UV finiteness
  - Scale dependence
- Separate the weak part

$$\sigma(bg \to bH)_{NLO} = \sigma(bg \to bH)_0 \left[1 + \Delta_{QCD} + \Delta_{QED} + \Delta_{WK}\right]$$

Loop Calculations $bg \to bH$





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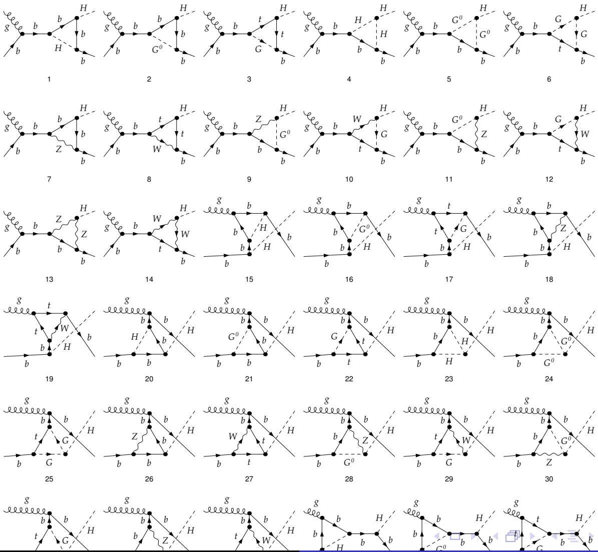
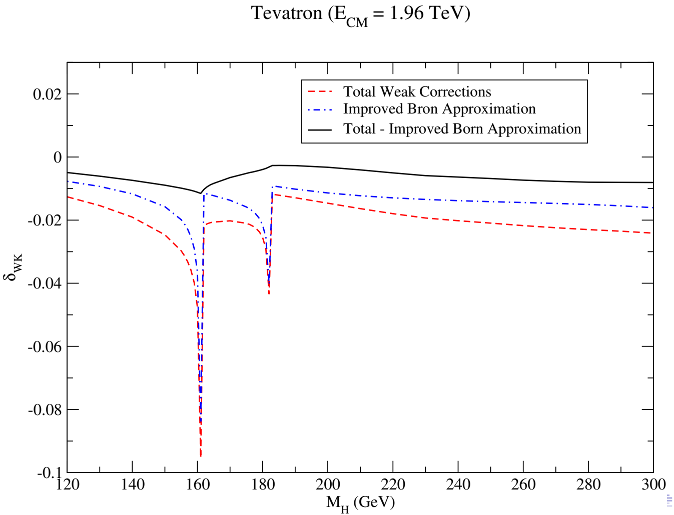
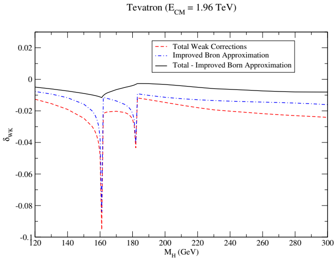


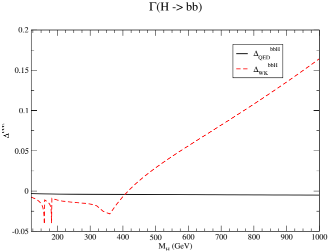
Results for Tevatron $bg \to bH$

$p_T > 20$ GeV and $|\eta| < 2.0$



Improved Born Approximation





- Calculate weak correction to $H \to b\bar{b}$

$$\Gamma(H \to b\bar{b})_{NLO} = \Gamma(H \to b\bar{b})_0 \left[1 + \Delta_{QCD}^{bbH} + \Delta_{QED}^{bbH} + \Delta_{WK}^{bbH}\right]$$

- Define IBA as

$$\sigma(bg \to bH)_{NLO} = \sigma(bg \to bH)_0 \left[1 + \Delta_{QCD}^{bbH} + \Delta_{QED}^{bbH} + \Delta_{WK}^{bbH}\right]$$

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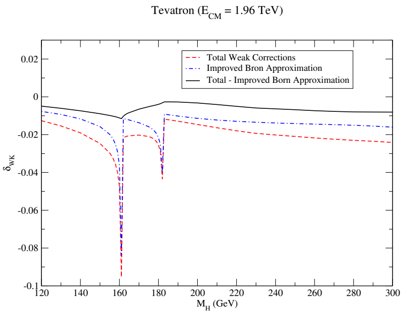
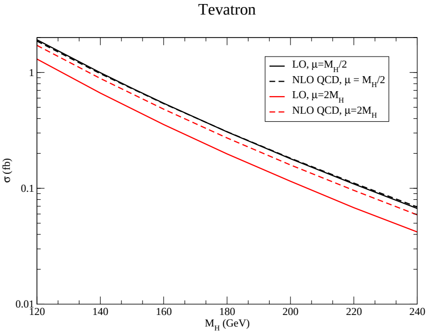
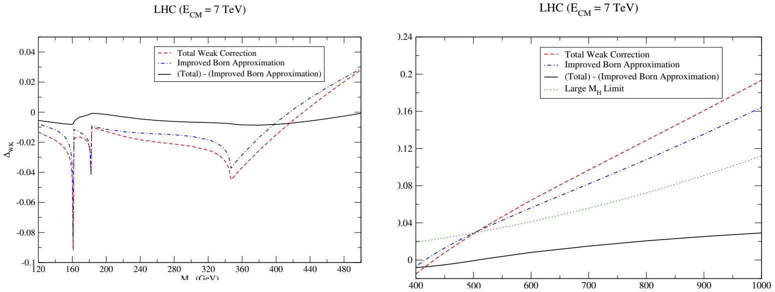




- Total weak corrections small (except near thresholds)
- Even smaller in IBA formalism (less than 1%)

Results for LHC ($\sqrt{s} = 7$ TeV) $bg \to bH$

$p_T > 25$ GeV and $|\eta| < 2.5$



- Total weak corrections small except near thresholds and large Higgs mass (~ 18% at 1 TeV).
- Even smaller in IBA formalism (less than 1% for $m_H < 500$ GeV)

Summary

- Associated Higgs-bottom production supressed in SM
- But important in models beyond SM where bottom Yukawa is enhanced.
- Some general features of weak corrections for $bg \to bH$:
  - Weak corrections small except at thresholds and large m_H .
  - IBA (corrections from bbH) is a good approximation.

- Outlook
  - Investigate BSM weak corrections where b yukawa is enhanced.
  - [arXiv:1005.0759, Beccaria et al : Electroweak one-loop calculation in MSSM]